State of California
Office of Administrative Law

In re:
State Water Resources Control Board

Regulatory Action:

Title 23, California Code of Regulations

Adopt sections: **877, 877.1, 877.2, 877.3, 877.4, 877.5, 877.6, 878, 878.1, 879, 879.1, 879.2**
Amend sections:
Repeal sections:

NOTICE OF APPROVAL OF EMERGENCY REGULATORY ACTION

Government Code Sections 11346.1 and 11349.6

OAL Matter Number: 2021-0630-01

OAL Matter Type: Emergency (E)

The proposed emergency regulation would provide the State Water Resources Control Board's Division of Water Rights and users within the Russian River watershed a methodology for determining the extent to which water is unavailable for diversion at water users' priority of right. It would also authorize the Deputy Director to issue curtailment orders requiring recipients to cease diversions unless and until (1) they have authorization to continue diverting pursuant to one of the exceptions enumerated in the regulation, or (2) they receive notice that the curtailment order has been lifted.

The emergency regulation would provide the State Water Resources Control Board's Deputy Director for the Division of Water Rights authority to implement curtailment actions in the event that Lake Mendocino storage targets are not met (for Upper Russian River watershed curtailments) or when flows are insufficient to support all water right priorities (for Lower Russian River watershed curtailments). The proposed regulations also: define non-consumptive uses and minimum human health and safety needs; provide a pathway to allow for continued diversions for non-consumptive uses; provide procedures for authorizing continued diversion to meet minimum human health and safety needs; and establish reporting requirements for water right holders issued a curtailment notice.

OAL approves this emergency regulatory action pursuant to sections 11346.1 and 11349.6 of the Government Code.

This emergency regulatory action is effective on 7/12/2021 and, pursuant to Water Code section 1058.5(c), will expire on 7/12/2022. The Certificate of Compliance for this action is due no later than 7/11/2022.

Date: July 12, 2021

Dale P. Mentink
Senior Attorney

Original: Eileen Sobeck, Executive Director
Copy: Andrew Deeringer

For: Kenneth J. Pogue
Director

STATE OF CALIFORNIA--OFFICE OF ADMINISTRATIVE LAW

NOTICE PUBLICATION/REGULATIONS SUBMISSION

EMERGENCY

STD. 400 (REV. 10/2019)

For use by Secretary of State only

ENDORSED - FILED
In the office of the Secretary of State
of the State of California

JUL 12 2021

1:18pm

OAL FILE NUMBERS	NOTICE FILE NUMBER	REGULATORY ACTION NUMBER	EMERGENCY NUMBER
	Z-		2021-0630-01E

For use by Office of Administrative Law (OAL) only

NOTICE

2021 JUN 30 P 1:47

OFFICE OF ADMINISTRATIVE LAW

REGULATIONS

AGENCY WITH RULEMAKING AUTHORITY
State Water Resources Control Board

AGENCY FILE NUMBER (If any)

A. PUBLICATION OF NOTICE (Complete for publication in Notice Register)

1. SUBJECT OF NOTICE	TITLE(S)	FIRST SECTION AFFECTED	2. REQUESTED PUBLICATION DATE
Diversion Curtailment,Russian River Watershed	23	877	

3. NOTICE TYPE
[X] Notice re Proposed Regulatory Action [ ] Other

4. AGENCY CONTACT PERSON
Andrew Deeringer

TELEPHONE NUMBER
(916) 539-2132

FAX NUMBER (Optional)

OAL USE ONLY — ACTION ON PROPOSED NOTICE: [ ] Approved as Submitted [ ] Approved as Modified [ ] Disapproved/Withdrawn

NOTICE REGISTER NUMBER

PUBLICATION DATE

B. SUBMISSION OF REGULATIONS (Complete when submitting regulations)

1a. SUBJECT OF REGULATION(S)
Emergency Actions to Protect Water Supplies and Threatened and Endangered Fish in the Russian River Watershed

1b. ALL PREVIOUS RELATED OAL REGULATORY ACTION NUMBER(S)

2. SPECIFY CALIFORNIA CODE OF REGULATIONS TITLE(S) AND SECTION(S) (Including title 26, if toxics related)

SECTION(S) AFFECTED (List all section number(s) individually. Attach additional sheet if needed.)

ADOPT
877, 877.1, 877.2, 877.3, 877.4, 877.5, 877.6, 878, 878.1, 879, 879.1, and 879.2

om per agency request 7/12/21

AMEND

REPEAL

TITLE(S)
23

3. TYPE OF FILING

[ ] Regular Rulemaking (Gov. Code §11346)
[ ] Resubmittal of disapproved or withdrawn nonemergency filing (Gov. Code §§11349.3, 11349.4)
[X] Emergency (Gov. Code, §11346.1(b))
[ ] Certificate of Compliance: The agency officer named below certifies that this agency complied with the provisions of Gov. Code §§11346.2-11347.3 either before the emergency regulation was adopted or within the time period required by statute.
[ ] Resubmittal of disapproved or withdrawn emergency filing (Gov. Code, §11346.1)
[ ] Emergency Readopt (Gov. Code, §11346.1(h))
[ ] File & Print
[ ] Other (Specify)
[ ] Changes Without Regulatory Effect (Cal. Code Regs., title 1, §100)
[ ] Print Only

4. ALL BEGINNING AND ENDING DATES OF AVAILABILITY OF MODIFIED REGULATIONS AND/OR MATERIAL ADDED TO THE RULEMAKING FILE (Cal. Code Regs. title 1, §44 and Gov. Code §11347.1)

5. EFFECTIVE DATE OF CHANGES (Gov. Code, §§ 11343.4, 11346.1(d); Cal. Code Regs., title 1, §100)
[ ] Effective January 1, April 1, July 1, or October 1 (Gov. Code §11343.4(a))
[X] Effective on filing with Secretary of State
[ ] §100 Changes Without Regulatory Effect
[ ] Effective other (Specify)

6. CHECK IF THESE REGULATIONS REQUIRE NOTICE TO, OR REVIEW, CONSULTATION, APPROVAL OR CONCURRENCE BY, ANOTHER AGENCY OR ENTITY
[ ] Department of Finance (Form STD. 399) (SAM §6660)
[ ] Fair Political Practices Commission
[ ] State Fire Marshal
[ ] Other (Specify)

om per agency request 7/12/21

7. CONTACT PERSON	TELEPHONE NUMBER	FAX NUMBER (Optional)	E-MAIL ADDRESS (Optional)
Andrew Deeringer	(916) 539-2132		Andrew.Deeringer@waterboards

8. I certify that the attached copy of the regulation(s) is a true and correct copy of the regulation(s) identified on this form, that the information specified on this form is true and correct, and that I am the head of the agency taking this action, or a designee of the head of the agency, and am authorized to make this certification.

SIGNATURE OF AGENCY HEAD OR DESIGNEE
Eileen Sobeck Digitally signed by Eileen Sobeck Date: 2021.06.30 10:51:00 -07'00'

DATE
June 30, 2021

TYPED NAME AND TITLE OF SIGNATORY
Eileen Sobeck, Executive Director, State Water Resources Control Board

For use by Office of Administrative Law (OAL) only

ENDORSED APPROVED

JUL 12 2021

Office of Administrative Law

Curtailment of Diversions to Protect Water Supplies and Threatened and Endangered Fish in the Russian River Watershed

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In Title 23, Division 3, Chapter 2, Article 24, add Sections 877, 877.1, 877.2, 877.3, 877.4, 877.5, 877.6, 878, 878.1, 879, 879.1 and 879.2 to read:

Article 24. Curtailment of Diversions to Protect Water Supplies and Threatened and Endangered Fish in the Russian River Watershed

§ 877 [Reserved]

§ 877.1 Definitions

(a) "Curtailment Order" refers to an order from the Deputy Director of the Division of Water Rights ordering a water right holder to cease diversions.

(b) "Deputy Director" refers to the Deputy Director of the Division of Water Rights, or duly authorized designee, at the State Water Resources Control Board.

(c) "Flood Control District" refers to the Mendocino County Russian River Flood Control and Water Conservation Improvement District.

(d) "Lower Russian River" refers to the surface waters, including underflow and subterranean streams, of the Russian River downstream of the confluence of Dry Creek and the Russian River.

(e) "Lower Russian River Watershed" refers to the area in Sonoma County that drains towards Dry Creek and the area downstream of the confluence of the Russian River and Dry Creek that drains towards the outlet of the Russian River to the Pacific Ocean.

(f) "Mainstem of the Upper Russian River" refers to the surface waters, including underflow and subterranean streams, of the Upper Russian River downstream of Lake Mendocino and upstream of the confluence of Dry Creek and the Russian River.

(g) "Minimum human health and safety needs" refers to the amount of water necessary for prevention of adverse impacts to human health and safety, for which there is no feasible alternate supply. "Minimum human health and safety needs" include:

(1) Indoor domestic water uses including water for human consumption, cooking, or sanitation purposes. For the purposes of this article, water provided outdoors for human consumption, cooking, or sanitation purposes, including but not limited to facilities for unhoused persons or campgrounds, shall be regarded as indoor domestic water use. As necessary to provide for indoor domestic water use, water diverted for minimum human health and safety needs may include water hauling and bulk water deliveries, so long as the diverter maintains records of such deliveries and complies with the reporting requirements of Section 879, and so long as such provision is consistent with a valid water right.

(2) Water supplies necessary for energy sources that are critical to basic grid reliability, as identified by the California Independent System Operator, California Public Utilities Commission, California Energy Commission, or a similar energy grid reliability authority.

(3) Water supplies necessary to prevent tree die-off that would contribute to fire risk to residences, and for maintenance of ponds or other water sources for fire fighting, in addition to water supplies identified by the California Department of Forestry and Fire Protection or another appropriate authority as regionally necessary for fire preparedness.

(4) Water supplies identified by the California Air Resources Board, a local air quality management district, or other appropriate public agency with air quality expertise, as necessary to address critical air quality impacts to protect public health.

(5) Water supplies necessary to address immediate public health or safety threats, as determined by a public agency with health or safety expertise.

(6) Other water uses necessary for human health and safety which a state, local, tribal or federal health, environmental, or safety agency has determined are critical to public health and safety or to the basic infrastructure of the state. Diverters wishing to continue diversions for these uses must identify the health and safety need, include approval or similar relevant documentation from the appropriate public agency,

describe why the amount requested is critical for the need and cannot be met through alternate supplies, state how long the diversion is expected to continue, certify that the supply will be used only for the stated need, and describe steps taken and planned to obtain alternative supplies.

(h) "State Water Board" refers to the State Water Resources Control Board.

(i) "Upper Russian River" refers to the surface waters, including underflow and subterranean streams, of the Russian River upstream of the confluence of the Russian River and Dry Creek and includes both the East and West Forks of the Russian River.

(j) "Upper Russian River Watershed" refers to the area located in Mendocino and Sonoma Counties that drains towards the confluence of Dry Creek and the Russian River.

Authority: Sections 1058, 1058.5, Water Code

Reference: Cal. Const., Art., X § 2; Sections 100, 100.5, 104, 105, 106.3, 275, 1058.5, Water Code; *Environmental Defense Fund v. East Bay Muni. Util. Dist.* (1980) 26 Cal.3d 183.

§ 877.2 Emergency Curtailments Due to Lack of Water Availability in the Lower Russian River Watershed

(a) This section applies to water diversions in the Lower Russian River Watershed.

(b) After the effective date of this regulation, when flows in the Lower Russian River Watershed are insufficient to support all diversions, the Deputy Director may issue curtailment orders to water right holders, requiring the curtailment of water diversion and use.

(c) In determining the extent to which water is available under a diverter's priority of right or when rescinding curtailment orders, the Deputy Director shall consider:

(1) Relevant available information regarding date of priority, including but not limited to claims of first use in statements of water diversion and use, judicial and State Water Board decisions and orders, and other information contained in the Division of Water Rights files;

(2) Monthly water right demand projections based on reports of water diversion and use for permits and licenses, or statements of water diversion and use, from 2017 through 2019.

(3) Water availability projections based on one or more of the following:

(A) Outputs from a United States Geological Survey's Precipitation Runoff Modeling System model, calibrated by State Water Board staff to estimate current or historical natural cumulative runoff throughout the watershed, as well as forecasts of monthly supplies;

(B) Climatic estimates of precipitation and temperature from the Parameter-elevation Regressions on Independent Slopes Model, commonly referred to as PRISM;

(C) Historical periods of comparable conditions with respect to daily temperatures, precipitation, or surface flows;

(D) Outputs from the Santa Rosa Plain Hydrologic Model developed by United States Geological Survey; or

(E) Stream gage data, where available.

(4) The Deputy Director may also consider additional pertinent and reliable information when determining water right priorities, water availability, and demand projections.

(5) Evaluation of available supplies against demands may be performed at the downstream outlet of the Lower Russian River, or at a smaller sub-watershed scale using the Drought Water Rights Allocation Tool, or comparable tool. Use of the Drought Water Rights Allocation Tool will be in accordance with the formulations document for the Drought Water Rights Allocation Tool (March 2, 2020) and Drought Water Right Curtailment Analysis for California's Eel River (November 20, 2017), which are hereby incorporated by reference.

(d) Water users and water right holders are responsible for checking the State Water Board's drought announcements website and signing up for the email distribution list referenced in subdivision (e)(2) to receive updated water supply forecasts. It is anticipated that forecasts of water supplies available to meet water rights demands will be updated on a monthly basis until cumulative rainfall of greater than 0.5 inches occurs as measured at Healdsburg, California. Following this precipitation event, it is anticipated that forecasts of supplies will be updated on a weekly basis until rescission of all curtailment orders under this section.

(e) (1) Initial curtailment orders will be sent to each water right holder or the agent of record on file with the Division of Water Rights. The water right holder or agent of record is responsible for immediately providing notice of the curtailment order(s) to all diverters exercising the water right(s) covered by the curtailment order(s).

(2) The State Water Board has established an email distribution list that water right holders may join to receive drought notices, water supply forecasts, and updates regarding curtailments. Notice provided by email or by posting on the State Water Board's drought web page shall be sufficient for all purposes related to drought notices and updates regarding curtailment orders.

(f) Rescission of curtailment orders shall be announced using the email distribution list and web page described in subdivision (e).

Authority: Sections 1058, 1058.5, Water Code

Reference: Cal. Const., Art. X, § 2; Sections 100, 100.5, 104, 105, 275, 1058.5, Water Code; *National Audubon Society v. Superior Court* (1983) 33 Cal.3d 419; *Stanford Vina Ranch Irrigation Co. v. State of California* (2020) 50 Cal.App.5th 976.

§ 877.3 Emergency Curtailment Where Insufficient Flows are Available in the Upper Russian River Watershed

(a) This section applies to water diversions in the Upper Russian River Watershed.

(b) (1) The Deputy Director may issue a curtailment order upon a determination that the conditions in subdivision (c) are occurring. Curtailment orders shall be effective the day after issuance.

(2) If maintaining minimum flows required for the protection of minimum human health and safety needs, fish and wildlife, or further preserving stored water in Lake Mendocino for human health and safety needs would require curtailment of uses otherwise exempt from curtailment under this article, then the Deputy

Director shall consider whether those uses should be allowed to continue based on the most current information available regarding fish populations, human health and safety needs, and the alternatives available to protect both human health and safety and threatened or endangered fish. Curtailment of water uses under this subdivision (b)(2) and any updates regarding such curtailments shall be noticed as described in subdivision (d).

(c) When storage levels in Lake Mendocino are below those specified in section 877.4, and Sonoma County Water Agency is making Supplemental Storage Releases to satisfy Inbasin Uses, diversion of water within the Upper Russian River Watershed that does not meet an exemption identified in section 878 or section 878.1 constitutes an unreasonable use of water and is prohibited.

(1) Inbasin Uses are defined as diversions from the Mainstem of the Upper Russian River to meet minimum human health and safety needs, Reach Losses, and minimum flows required for protection of fish and wildlife as required by a water right permit or license term, including any enforceable modifications of the foregoing. Export diversions, deliveries scheduled by the Flood Control District pursuant to License 13898, and Reach Losses associated with those exports and deliveries are specifically excluded from the definition of Inbasin Uses.

(2) Supplemental Storage Releases are defined as water released from Lake Mendocino which is in excess of inflows to Lake Mendocino, as calculated on a daily basis, to satisfy Inbasin Uses.

(3) Reach Losses are defined as water that is lost from the Mainstem of the Upper Russian River due to riparian habitat, evaporative losses, or percolation to groundwater.

(d) (1) Initial curtailment orders will be sent to each water right holder or the agent of record on file with the Division of Water Rights. The water right holder or agent of record is responsible for immediately providing notice of the curtailment order(s) to all diverters exercising the water right(s) covered by the curtailment order(s).

(2) The State Water Board has established an email distribution list that water right holders may join to receive drought notices, water supply forecasts, and updates regarding curtailments. Notice provided by email or by posting on the State Water Board's drought web page shall be sufficient for all purposes related to drought notices and updates regarding curtailment orders.

Authority: Sections 1058, 1058.5, Water Code

Reference: Cal. Const., Art. X, § 2; Sections 100, 100.5, 104, 105, 275, 1058.5, Water Code; *National Audubon Society v. Superior Court* (1983) 33 Cal.3d 419; *Light v. State Water Resources Control Board* (2014) 226 Cal.App.4th 1463; *Stanford Vina Ranch Irrigation Co. v. State of California* (2020) 50 Cal.App.5th 976.

§ 877.4 Lake Mendocino Storage Levels

Curtailment orders for diversions in the Upper Russian River Watershed shall not be issued unless storage levels in Lake Mendocino fall below the following levels prior to the specified dates:

(a) 29,315 acre-feet before July 1.

(b) 27,825 acre-feet before July 15.

(c) 26,109 acre-feet before August 1.

(d) 24,614 acre-feet before August 15.

(e) 22,745 acre-feet before September 1.

(f) 21,251 acre-feet before September 15.

(g) 20,000 acre-feet on any date while the regulation is in effect.

Authority: Sections 1058, 1058.5, Water Code

Reference: Cal. Const., Art. X, § 2; Sections 100, 100.5, 104, 105, 109, 275, 1058.5, Water Code; *National Audubon Society v. Superior Court* (1983) 33 Cal.3d 419; *City of Barstow v. Mojave Water Agency* (2000) 23 Cal.4th 1224; *Stanford Vina Ranch Irrigation Co. v. State of California* (2020) 50 Cal.App.5th 976.

§ 877.5 Rescission of Curtailment Orders in Upper Russian River Watershed

(a) Following issuance of curtailment orders pursuant to section 877.3, the Deputy Director will notify water right holders of the extent to which curtailment orders will be rescinded following a determination by the Deputy Director that Sonoma County Water Agency is no longer making

Supplemental Storage Releases to satisfy Inbasin Uses and natural or abandoned flows are available.

(b) In determining the extent to which water is available under a diverter's priority of right when rescinding curtailment orders, the Deputy Director shall consider:

(1) Relevant available information regarding date of priority, including but not limited to claims of first use in statements of water diversion and use, judicial and State Water Board decisions and orders, and other information contained in the Division of Water Rights files;

(2) Monthly water right demand projections based on reports of water diversion and use for permits and licenses, or statements of water diversion and use, from 2017 through 2019.

(3) Water availability projections based on one or more of the following:

(A) Outputs from a United States Geological Survey's Precipitation Runoff Modeling System model, calibrated by State Water Board staff to estimate current or historical natural cumulative runoff throughout the watershed, as well as forecasts of monthly supplies.

(B) Climatic estimates of precipitation and temperature from the Parameter-elevation Regressions on Independent Slopes Model, commonly referred to as PRISM.

(C) Historical periods of comparable conditions with respect to daily temperatures, precipitation, or surface flows.

(D) Outputs from the Santa Rosa Plain Hydrologic Model developed by United States Geological Survey; or

(E) Stream gage data, where available.

(4) The Deputy Director may also consider additional pertinent and reliable information when determining water right priorities, water availability and demand projections.

(5) Evaluation of available supplies against demands may be performed at the downstream outlet of either the Upper Russian River or the

Lower Russian River, or at a smaller sub-watershed scale using the Drought Water Rights Allocation Tool, or comparable tool. Use of the Drought Water Rights Allocation Tool will be in accordance with the formulations document for the Drought Water Rights Allocation Tool (March 2, 2020) and Drought Water Right Curtailment Analysis for California's Eel River (November 20, 2017), which are hereby incorporated by reference.

(c) Water users and water right holders are responsible for checking the State Water Board's drought announcements website and signing up for the email distribution list referenced in section 877.3, subdivision (e)(2), to receive updated water supply forecasts. It is anticipated that forecasts of water supplies available to meet water rights demands will be updated on a monthly basis until cumulative rainfall of greater than 0.5 inches occurs as measured at Ukiah Municipal Airport precipitation stations within the watershed. Following this precipitation event, it is anticipated that forecasts of supplies will be updated on a weekly basis until rescission of all curtailment orders under this section.

(d) Rescission of a curtailment order shall be announced using the email distribution list and web page described in section 877.3, subdivision (e)(2).

Authority: Sections 1058, 1058.5, Water Code

Reference: Cal. Const., Art. X, § 2; Sections 100, 100.5, 104, 105, 275, 1058.5, Water Code; *National Audubon Society v. Superior Court* (1983) 33 Cal.3d 419; *Light v. State Water Resources Control Board* (2014) 226 Cal.App.4th 1463; *Stanford Vina Ranch Irrigation Co. v. State of California* (2020) 50 Cal.App.5th 976.

§ 877.6 Rediversion of Water Previously Stored in Lake Mendocino

(a) Rediversion by the Flood Control District of previously stored water released from Lake Mendocino shall be an unreasonable use of water and subject to the enforcement provisions described in section 879.2 unless such rediversion meets the requirements of this section.

(b) The Flood Control District shall schedule all deliveries of water pursuant to License 13898 at least one week in advance of release of the water.

(c) The timing of rediversion activities relative to release of water shall be based on a travel time of water along the Russian River agreed upon between the Flood Control District and Sonoma County Water Agency.

(d) The Flood Control District shall provide a monthly schedule of rediversions by the first day of each month and shall confirm by noon on Friday of each week whether those diversions will occur in the following week or have changed.

(e) No rediversions shall occur following September 1 unless Sonoma County Water Agency and the Flood Control District have jointly submitted an executed agreement to the Deputy Director specifying the amount of water stored in Lake Mendocino pursuant to License 13898, the amount of water that will remain stored in Lake Mendocino for use in 2022, and a methodology acceptable to the Deputy Director for determining how inflows to Lake Mendocino are attributed to the Flood Control District and SCWA's respective water rights.

Authority: Sections 1058, 1058.5, Water Code

Reference: Cal. Const., Art. X, § 2; Sections 100, 100.5, 104, 105, 275, 1058.5, Water Code; *National Audubon Society v. Superior Court* (1983) 33 Cal.3d 419; *Light v. State Water Resources Control Board* (2014) 226 Cal.App.4th 1463; *City of Barstow v. Mojave Water Agency* (2000) 23 Cal.4th 1224.

§ 878. Non-Consumptive Uses

Diversion and use described in this section under any valid basis of right may continue after issuance of a curtailment order without further approval from the Deputy Director, subject to the conditions set forth in this section. Diversions described in this section may not be required to curtail in response to a curtailment order under this article if their diversion and use of water does not decrease downstream flows. Any diverter wishing to continue diversion under this subdivision must submit to the Deputy Director a certification, under penalty of perjury, which describes the non-consumptive use and explains, with supporting evidence, how the diversion and use do not decrease downstream flows in the applicable watershed. The Deputy Director may request additional information or disapprove any certification if the information provided is insufficient to support the statement or if more convincing evidence contradicts the claims. If a certification submitted pursuant to this section is disapproved, the diversions are subject to any curtailment order issued for that basis of right. This section applies to:

(a) Direct diversions solely for hydropower if discharges are returned to the Russian

River or its tributaries and water is not held in storage.

(b) Direct diversions dedicated to instream uses for the benefit of fish and wildlife pursuant to Water Code section 1707, including those that divert water to a different location for subsequent release, provided the location of release is hydraulically connected to the Russian River.

(c) Direct diversions where the Deputy Director, the California Department of Fish and Wildlife, and the Executive Officer of the North Coast Regional Board have approved a substitution of releases of either stored water or groundwater into the Russian River or a tributary thereof for the benefit of fish and wildlife such that there is not a net decrease in stream flow as a result of the diversion at the next downstream USGS gage. The rate of releases made pursuant to this subdivision must be measured daily using a device or measurement method approved by the Deputy Director and provided to the Deputy Director on a monthly basis. Proposals involving the release of groundwater shall provide sufficient data and information to reasonably quantify any depletions of surface water caused by the groundwater pumping, the potential time lags of those depletions, and if additional groundwater releases beyond the diversion amounts are able to offset those depletions. The release of water does not have to be conducted by the owner of the water right proposed for the continued diversions, provided an agreement between the water right holder and the entity releasing the water is included in the proposal.

(d) Other direct diversions solely for non-consumptive uses, if those diverters file with the Deputy Director a certification under penalty of perjury demonstrating that the diversion and use are non-consumptive and do not decrease downstream flows in the watershed.

Authority: Sections 1058, 1058.5, Water Code

Reference: Cal. Const., Art. X, § 2; Sections 100, 187, 275, 348, Water Code

§ 878.1 Minimum Human Health and Safety Needs

(a) Diversions described in this section under any valid basis of right may be authorized to continue after issuance of a curtailment order, subject to the conditions set forth in this section. A diversion that would otherwise be subject to curtailment may be authorized if:

(1) The diversion is necessary for minimum human health and safety needs;

and therefore,

(2) The diversion is necessary to further the constitutional policy that the water resources of the state be put to beneficial use to the full extent they are capable, and that waste and unreasonable use be prevented, notwithstanding the effect of the diversions on more senior water rights or instream beneficial uses.

(b) (1) Diversions for minimum human health and safety needs under any valid basis of right of not greater than 55 gallons per person per day may continue after issuance of a curtailment order without further approval from the Deputy Director, subject to the conditions set forth in this section. Any diverter wishing to continue diversion under this subdivision must submit to the Deputy Director certification, under penalty of perjury, of compliance with the requirements of subdivisions (b)(1)(A)-(E), below. The Deputy Director may request additional information or set additional requirements on continued diversion.

(A) Not more than 55 gallons per person per day will be diverted under all bases of right.

(B) The diversion is necessary to serve minimum human health and safety needs as defined in section 877.1, subdivision (g), after all other alternate sources of water have been used. To the extent other water sources are available, those sources will be used first and the total used will not exceed 55 gallons per person per day.

(C) The diverter and all end users of the diverted water are operating under the strictest existing conservation regime for that place of use, if such a plan exists for the area or service provider, or shall be operating under such regime within 30 days. If additional approvals are required before implementation of the conservation regime, the diverter must certify that all possible steps will be taken immediately to ensure prompt approval.

(D) If the diverter is distributor of a public water supply under Water Code sections 350 et seq., that it has declared a water shortage emergency condition and either already has adopted regulations and restrictions on the delivery of water or will adopt conservation and water delivery restrictions and regulations within a timeframe specified by the Deputy Director as a condition of certification.

(E) The diverter has either pursued steps to acquire other sources of water, but has not yet been completely successful, as described in an attached report, or the diverter will pursue the steps in an attached plan to identify and secure additional water.

(2) To the extent that a diversion for minimum human health and safety needs requires more than 55 gallons per person per day, the continued diversion of water after issuance of a curtailment order for the diversion requires submission of a petition demonstrating compliance with the requirements of subdivisions (b)(2)(A)-(F), below, and approval by the Deputy Director. The Deputy Director may condition approval of the petition on implementation of additional conservation measures and reporting requirements. Any petition to continue diversion to meet minimum human health and safety needs of more than 55 gallons per person per day must:

(A) Describe the specific circumstances that make the requested diversion amount necessary to meet minimum human health and safety needs, if a larger amount is sought.

(B) Estimate the amount of water needed.

(C) Certify that the supply will be used only for the stated need.

(D) Describe any other additional steps the diverter will take to reduce diversions and consumption.

(E) Provide the timeframe in which the diverter expects to reduce usage to no more than 55 gallons per person per day, or why minimum human health and safety needs will continue to require more water.

(F) As necessary, provide documentation that the use meets the definition of minimum human health and safety needs provided in subdivision (g) of section 877.1.

(c) For public water systems with 15 or greater connections and small water systems of 5 to 15 connections, gallons per person per day shall be calculated on a monthly basis and the calculation methodology shall be consistent with the State Water Board's Percentage Residential Use and Residential Gallons Per Capita Daily Calculation (PRU and R-GPCD Calculation), dated September 22, 2020, which is hereby incorporated by reference.

(d) Diversions for minimum human health and safety needs that cannot be quantified on the basis of an amount per person per day require a petition and approval from the Deputy Director. The Deputy Director may approve a such a petition under this subdivision or subdivision (b)(2) upon a finding that the petition demonstrates that the requested diversion is in furtherance of the constitutional policy that the water resources of the state be put to beneficial use to the full extent they are capable, and that waste and unreasonable use be prevented, notwithstanding the effect of the diversion on senior water rights or instream beneficial uses, and may condition approval as appropriate to ensure that the diversion and use are reasonable and in the public interest.

(e) To the extent necessary to resolve immediate public health or safety threats, a diversion subject to a curtailment order may continue while a petition under subdivision (b)(2) or (d) is being prepared and is pending. The Deputy Director may require additional information to support the initial petition, information on how long the diversion is expected to continue, and a description of other steps taken or planned to obtain alternative supplies.

(f) Notice of certification, petitions, and decisions under this section and section 878 will be posted as soon as practicable on the State Water Board's drought webpage. The Deputy Director may issue a decision under this article prior to providing notice.

(g) Diversion and use within the Russian River Watershed that deprives water for minimum human health and safety needs in 2021, or which creates unacceptable risk of depriving water for minimum human health and safety needs in 2022, is an unreasonable use of water. The Deputy Director shall prevent such unreasonable use of water by implementing the curtailment methodology described in section 877.2 for diversions in the Lower Russian River Watershed and sections 877.3, 877.4, 877.5, and 877.6 for diversions in the Upper Russian River Watershed.

Authority: Sections 1058, 1058.5, Water Code

Reference: Cal. Const., Art. X, § 2; Sections 100, 100.5, 104, 105, 106.3, 275, 1058.5, Water Code; *Environmental Defense Fund v. East Bay Muni. Util. Dist.* (1980) 26 Cal.3d 183; *Light v. State Water Resources Control Board* (2014) 226 Cal.App.4th 1463; *Stanford Vina Ranch Irrigation Co. v. State of California* (2020) 50 Cal.App.5th 976.

§ 879. Reporting

(a) All water right holders issued a curtailment order under this article are required, within seven calendar days, to submit under penalty of perjury a certification of one or more of the following actions taken in response to the curtailment order, certifying, as applicable, that:

(1) Diversions under the water right(s) identified have ceased;

(2) Any continued use is under other water rights not subject to curtailment, specifically identifying those other rights, including the basis of right and quantity of diversion;

(3) Diversions under the water right(s) identified continue only to the extent that they are non-consumptive uses for which a certification for continued diversion has been submitted as specified in section 878;

(4) Diversions under the water right(s) identified continue only to the extent that they are to provide for minimum human health and safety needs, a certification has been filed as authorized under section 878.1, subdivision (b)(1), and the subject water right authorizes the diversion in the absence of a curtailment order; or

(5) Diversions under the water right(s) identified continue only to the extent that they are consistent with a petition filed under section 878.1, subdivision (b)(2) or (d), and diversion and use will comply with the conditions for approval of the petition.

(b) All water users or water right holders whose continued diversion may be authorized under section 878.1 are required to submit, under penalty of perjury, information identified on a schedule established by the Deputy Director as a condition of certification or petition approval. The required information may include, but is not limited to, the following:

(1) The water right identification numbers under which diversions continue.

(2) How the diverter complies with any conditions of continued diversion, including the conditions of certification under section 878.1, subdivision (b)(1);

(3) Any failures to comply with conditions, including the conditions of certification under section 878.1, subdivision (b)(1), and steps taken to prevent further violations;

(4) Conservation and efficiency efforts planned, in the process of implementation, and implemented, as well as any information on the effectiveness of implementation;

(5) Efforts to obtain alternate water sources;

(6) If the diversion is authorized under an approved petition filed pursuant to section 878.1, subdivision (b)(2), progress toward implementing the measures imposed as conditions of petition approval;

(7) If the diversion is authorized under section 878.1, subdivision (d):

(A) The rate of diversion if it is still ongoing;

(B) Whether the water has been used for any other purpose; and

(C) The date diversion ceased, if applicable.

(8) The total water diversion for the reporting period and the total population served for minimum human health and safety needs. The total population must include actual or best available estimates of external populations not otherwise reported as being served by the water right holder, such as individuals receiving bulk or hauled water deliveries for indoor water use.

(9) Diversion amounts for each day in acre-feet per day, maximum diversion rate in cubic feet per second, and anticipated future daily diversion amounts and diversion rates.

(c) The Deputy Director, or delegee, may issue an order under this article requiring any person to provide additional information reasonably necessary to assess their compliance with this article. Any person receiving an order under this subdivision shall provide the requested information within the time specified by the Deputy Director, but not less than five (5) days.

Authority: Sections 348, 1058, 1058.5, Water Code

Reference: Sections 100, 187, 275, 348, 1051, 1058.5, 1841 Water Code

§ 879.1. Conditions of permits, licenses and registrations

Compliance with this article, including any conditions of certification or approval of a petition under this article, shall constitute a condition of all water right permits, licenses, certificates and registrations for diversions in the Russian River Watershed.

Authority: Sections 1058, 1058.5, Water Code

Reference: Cal. Const., Art. X, § 2; Sections 275, 1253, 1058.5, Water Code; *National Audubon Society v. Superior Court* (1983) 33 Cal.3d 419.

§ 879.2. Compliance and Enforcement

(a) A diverter must comply with a curtailment order issued under this article, any conditions of certification or approval of a petition under this article, and any water right condition under this article, notwithstanding receipt of more than one curtailment order. To the extent of any conflict between applicable requirements, the diverter must comply with the requirements that are the most stringent.

(b) Diversion or use of water in the Upper Russian River Watershed in violation of this article constitutes an unreasonable use of water and is subject to any and all enforcement proceedings authorized by law.

(c) Diversion or use of water in the Lower Russian River Watershed in violation of this article is a trespass under Water Code section 1052 and shall constitute evidence of diversion or use in excess of a water user's rights.

(d) All violations of this article shall be subject to any applicable penalties under Water Code section 1058.5. Nothing in this section shall be construed as limiting the enforceability of or penalties available under any other applicable provision of law.

Authority: Sections 1058, 1058.5, Water Code

Reference: Cal. Const., Art. X, § 2; Sections 275, 1052, 1055, 1058.5, 1825, 1831, Water Code; *National Audubon Society v. Superior Court* (1983) 33 Cal.3d 419.

DROUGHT WATER RIGHTS ALLOCATION TOOL MARCH 2, 2020

RIPARIAN FORMULATION

$$0 \leq P_k \leq 1$$

for all basins, *k*

Basin proportions *Pk* are between 0 and 1.

$$A_i = P_k u_i$$

for all *i* users, in each basin *k*

Each user's allocation A_i is user *i*'s basin proportion P_k, of *i*'s demand u_i.

$$\sum_{i \in k} A_i \leq v_k - e_k$$

for all *i* users that are within each basin *k*

Mass Balance: within every basin *k*, the sum of all users' allocations are less than or equal to flow v_k in basin *k*, less any environmental instream flow requirement e_k.

$$P_j \leq P_k$$

for all basins *j* and all basins *k*

Upstream basin proportions P_j cannot exceed downstream basin proportions P_k.

$$w_k = \frac{n_i}{n_{i\ at\ basin\ outlet}}$$

for all users, *i*

A basin penalty w_k is applied that increases with the ratio of the number of users n_i upstream of basin *k*, to the number of users at the watershed outlet $n_{i\ at\ basin\ outlet}$.

Why?

- Because if upstream basins are not allowed to exceed downstream basins, then some offset is required so that downstream basins are not allocated more than upstream, to conform with the riparian doctrine of shared shared shortage.

$$\alpha < Min\left(\frac{w_k}{u_k}\right)$$

for all basins, *k*

The basin scalar α is the minimum of the ratios between downstream penalties w_k and basin-wide demands u_k.

Why?

- Because.

Riparian Objective Function:

$$\text{Minimize } z = -\sum_i A_i + \alpha \sum_k w_k P_k$$

For all users *i*, and all basins, *k*

Minimize shortage (left term) + but make the slightly modified sum of basin proportions as large as possible (right term).

APPROPRIATIVE FORMULATION

$$0 \leq A_i \leq u_i$$

for all users, *i*

Each appropriative user's allocation A_i must be between 0 and her reported demand u_i

$$\sum_{i \in k} A_{i,(appropriative)} \leq v_k - e_k - \sum_{i \in k} A_{i,(riparian)}$$

for all users *i*, in all upstream basins *k*

Mass Balance: the sum of all appropriative allocations $A_{i,appropriative}$ that are in basin *k*, must be less than or equal to available flow *vk*, less any environmental instream flow requirement e_k, less the sum of all upstream riparian allocations, $A_{i,riparian}$.

Appropriative Objective Function:

$$\text{Minimize } z = \sum_i p_i(u_i - A_i)$$

for all users, *i*

Minimize the difference between demand and allocation, or shortage, $(u_i - A_i)$ weighted by the inverse of the priority of user *i*.

Drought Water Right Curtailment Analysis for California's Eel River

Benjamin Lord, A.M.ASCE[1]; Bonnie Magnuson-Skeels[2]; Andrew Tweet, A.M.ASCE[3]; Chad Whittington[4]; Lauren Adams, S.M.ASCE[5]; Reed Thayer, A.M.ASCE[6]; and Jay Lund, Dist.M.ASCE[7]

Abstract: Water users in California's hybrid water rights system have different legal priorities to available surface water in times of water scarcity. A set of two linear programming models was developed to determine curtailments of water use under drought conditions according to riparian and appropriative water right doctrines with spatially varying water availability and water rights within a basin. The models were implemented in spreadsheets and extended to estimate water right reliability and factors of safety in water rights administration. Alternate methods for calculating water use curtailments are discussed. Curtailments from the models are compared with actual water shortage notices issued by the state for the Eel River, California for June 30, 2014. Analyzing water use curtailments with an algorithm in spreadsheet software offers a mechanistic, transparent, accessible, and precise approach derived from legal doctrines to support water rights administration during drought. **DOI: 10.1061/(ASCE)WR.1943-5452.0000820.** © *2017 American Society of Civil Engineers.*

Introduction

Droughts often require users to curtail their water right diversions. Escriva-Bou et al. (2016) reviewed the curtailment of water rights, requiring some water rightholders to cease or reduce diversions, in various western states and arid countries. The present paper provides mathematical formulations and an example application of formal methods to fully allocate limited water supplies in California's hybrid system of surface-water rights. The proposed approach mathematically represents the logic of riparian and appropriative water law doctrines for a basin with spatially varying available water supply and water demands. By representing California's water rights law as an allocation algorithm using linear programming, this drought water rights allocation tool (DWRAT) provides a precise, timely, and transparent analytical framework for the complicated and often controversial process of curtailing water rights use during drought.

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California's Water Rights and Drought

Surface-water rights in California predominantly follow prior appropriation and riparian water law doctrines. Riparian rights were introduced by the adoption of English common law under California's constitution. Riparian rightholders are equal in priority and entitled to the natural flow of the water body for direct uses on their riparian land, without storage, so long as downstream users are not "unreasonably affected." The doctrine of prior appropriation was developed for resolving water claim disputes for available water among miners diverting water from streams for uses sometimes far from the point of diversion, possibly involving diversions to storage. The principle of "first in time, first in right" determines priority among appropriative water rights; early diverters have a higher priority than later diverters (Kanazawa 2015). To resolve growing conflicts among water rightholders, the 1886 California Supreme Court Case *Lux v. Haggin* ruled that riparian water rights categorically have a higher priority than appropriative water rights.

The 1913 California Water Commission Act (effective in 1914) established the predecessor of today's State Water Resources Control Board (SWRCB) to organize all new appropriations of water. All appropriative water right claims after this Act came into effect are post-1914 appropriative water rights. Rights with dates of first use before January 1, 1914, are known as pre-1914 rights. Riparian rights are established as a class, share shortages proportionally among each other, and have higher priority than any appropriative rights (Kanazawa 2015; Attwater and Markle 1987).

Over the next century, the SWRCB granted water right allocations exceeding five times the state's mean annual runoff (Grantham and Viers 2014). Water rights in basins with particularly high allocations relative to natural availability, such as the Scott River, have been explicitly adjudicated as a result of legal conflicts among rightholders. Overallocation (allocating more water than is normally available), coupled with the extensive impoundment of California rivers, decreases flow variability, which in turn damages aquatic and riparian ecosystems (Kondolf and Batalla 2005). Grantham et al. (2014) demonstrated the need for transparent strategies during drought water years to preserve environmental flow protections while reducing water use in an equitable manner.

Despite longstanding legal authority, the SWRCB first declared water shortages in 1977, and then not again until 2014. The year

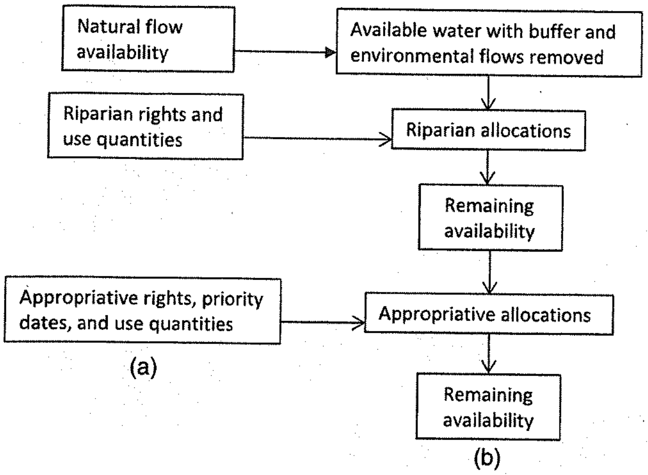

Fig. 1. DWRAT data flow: (a) input data; (b) allocation models

2014 was the third consecutive year of drought in California, and the SWRCB issued mandatory curtailments (formally called water shortage notices), supported by a declaration of drought emergency by Governor Jerry Brown. In May 2014, the Scott River was the first watershed with issued curtailments. In the following months, junior right holders in the Sacramento, San Joaquin, Russian, and Eel River Basins also were curtailed.

Water Allocation Models

Several previous water allocation models have used water rights for prioritizing users and demands (Wang et al. 2007). The Texas water availability modeling (WAM) system (Wurbs 2005) allocates streamflow and reservoir storage among rightholders with a prior appropriation doctrine. Many models represent priority-based water operations with different delivery, flow, and storage priorities (Sigvaldson 1976), such as *CalSim* (Draper et al. 2004) and *ModSim* (Fredericks et al. 1998). Linear or network flow optimization often are used to represent priority-based operations. Appropriative water right priorities can be represented through cost coefficients, with junior lower-priority rights having lower penalties for shortage. Israel and Lund (1999), Ferreira (2007), and Chou and Wu (2014) extended this approach with algorithms for determining cost coefficients accounting for return flows.

Despite an extensive body of literature on mathematically allocating water under the appropriative doctrine, few published methods exist on allocation under the riparian doctrine. In California, riparian water rightholders (riparians) are equal in priority to each other but categorically have a higher priority than appropriative water rightholders (appropriators).

Drought Water Rights Allocation Tool Formulation

DWRAT allocates water for rights under both major doctrines using spreadsheets and a free and open-source solver platform. DWRAT operates in two phases. The first phase distributes available water proportionally among riparian rightholders. The second phase allocates remaining available surface water by strict priority among appropriative rightholders. In both phases, water users are scattered over a network of subbasins with local water availabilities (initially without return flows). Total flow v into subbasin k is represented by v_k. Each user i has a normal use of u_i and receives water allocation A_i. Riparian users have unranked equal priority. Curtailment decisions among riparians limit diversions to a proportion of normal individual use varying by subbasin P_k, with a weighted penalty coefficient of w_k. These proportions determine a user's shortage. The shortage penalty weight per subbasin w_k increases with the number of upstream basins u_k to balance proportions across subbasins. Appropriative users have fixed priorities established by water right seniority. The unit shortage penalty p_i increases with seniority of right; minimizing shortages to senior rightholders reduces total penalty more than to junior rightholders. To assess allocations having mixed riparian and appropriative water rights, the riparian linear program is run first, followed by the appropriative linear program.

This overall approach represents the logic of each water law doctrine mathematically to allow implementation in software. Fig. 1 illustrates DWRAT's data flow. DWRAT models are run for a single daily time step, large enough to avoid issues of hydrologic routing for small basins.

Riparian Allocation Formulation

Riparian rightholders are equal in priority with water shortages distributed by restricting use proportionally across all basin users. Locally varying water availability can lead to differing proportional shortages within a basin. The following equations represent the logic of riparian water allocation. The allocation A_i for a riparian user i is defined in Eq. (1)

$$A_i = P_k u_i, \quad \forall\ i, i \in k \tag{1}$$

where all users in a subbasin k receive the same allocation proportion P_k of demand u_i, where P_k = decision variable. The subbasin allocation proportion P_k is constrained between zero and one [Eq. (2)], enforcing allocations between zero and normal use

$$0 \le P_k \le 1, \quad \forall\ k \tag{2}$$

The sum of all allocations (net diversions) upstream of a subbasin outlet cannot exceed the total availability of water leaving the subbasin. Total availability is inflows upstream of the subbasin outlet v_k minus environmental outflow flow requirement e_k and buffer outflow b_k [Eq. (3)]. Environmental flows, specified by the user, occur as a constraint. Alternatively, environmental flows could be represented as a water right with a relative priority. Buffer flow is used as a factor of safety to incorporate errors in water availability and actual uses

$$\sum_{i \in k} A_i \le v_k - e_k - b_k, \quad \forall\ k \tag{3}$$

The riparian objective function [Eq. (4)] maximizes total water allocations, with a weighting term to enforce allocation proportionally among water users

$$\text{Minimize } z = \alpha \sum_k w_k P_k - \sum_i A_i \tag{4}$$

In drought, maximizing only total allocations for all riparian users can yield multiple optima. Upstream users could receive zero allocations despite local availability while downstream users receive full allocations. Alternatively, water available in upstream reaches could be allocated entirely to upstream users, with large shortages occurring downstream. Both outcomes fail to distribute water proportionally among riparian users. Therefore, weights are included in the objective function to enforce equitable proportional allocation of shortage among riparian rightholders. The following constraints define how equal proportionality of shortage with full allocation of available water is met.

Upstream users cannot have a lower shortage (higher P_k) than downstream users. If upstream users have less shortage than downstream users, some upstream use could be allocated downstream so both sets of users receive the same proportion of shortage. This constraint is implemented in Eq. (5), where the allocation proportion in any upstream subbasin j cannot exceed the proportion of any downstream subbasin k

$$P_j \leq P_k, \quad \forall\, k, j \in k \tag{5}$$

This constraint would need to change for cases where natural flow decreases downstream from net losses to groundwater or lake and wetland evaporation.

All riparian users with local non-zero availability should receive allocations greater than zero. To prevent upstream users receiving zero allocations despite local availability and downstream users receiving large allocations because of increased availability (from not allocating that same water upstream), a weight is given to increasingly penalize high allocation proportions in downstream basins [Eq. (6)]. The downstream penalty w_k increases with the number of subbasins n_k upstream of subbasin k's outlet

$$w_k = \frac{n_k}{n_{k,\text{system outlet}}} \tag{6}$$

The sum of the products of these weights and allocation proportions is further weighted in the objective function to allocate all available water proportionally. To prioritize allocating all water, the equality terms are given less weight. The weigh α cannot exceed the minimum of all subbasin ratios of unit downstream penalty to total upstream demand [Eq. (7)]

$$\alpha < Min\left(\frac{w_k}{u_k}\right) \quad \forall\, k \tag{7}$$

Eqs. (5)–(7) provide counteracting weights to distribute a shortage equally across a watershed while maximizing total allocations to riparian users.

Riparian Allocation Example

The example watershed in Fig. 2 was created to test and demonstrate the riparian allocation linear program. Each of the eight subbasins (denoted A–H) has local inflows. Available streamflow is given for the outlet of each subbasin, with a fixed fraction for environmental flows. Flow characteristics are given in Table 1 and user demands in Table 2.

Tables 2 and 3 provide user and basin results from the riparian water rights allocation model. Comparing allocations in Subbasins A and B offers insight into the riparian allocation mechanics. Basin A has a total upstream demand of 18 and a local availability of 5.6. If all flow available in A is allocated to users in A, users would receive an allocation proportion of 0.31 (ratio of upstream demand to availability). Basin B has a local availability of 5.6 and upstream demand of 8. If B's availability was completely allocated locally, User 3 would receive an allocation proportion of 0.7, which exceeds downstream ratios of supply to demand. Thus, B is curtailed further to reduce the shortage proportion downstream. No greater shortages occur downstream of Basin A, so all available flow is allocated locally. If unallocated flow is zero, upstream shortage exceeds potential downstream shortages. Availability directly limits upstream allocation and constraint Eq. (3) binds. If unallocated flow exists, water is retained to minimize more severe shortages downstream.

The allocation proportion of 0.67, dictated by binding water availability (no unallocated flow) in Catchment F, is extended upstream to Catchments B, C, D, and E, showing an even allocation of shortage across the larger area. Basins A and G have lower allocation proportions from more severe local shortages. Basin H has a binding water availability that forces an allocation proportion of 0.7, but this does not extend upstream because of still tighter shortages upstream. All available flow was allocated to users, with no nonenvironmental flow leaving the system.

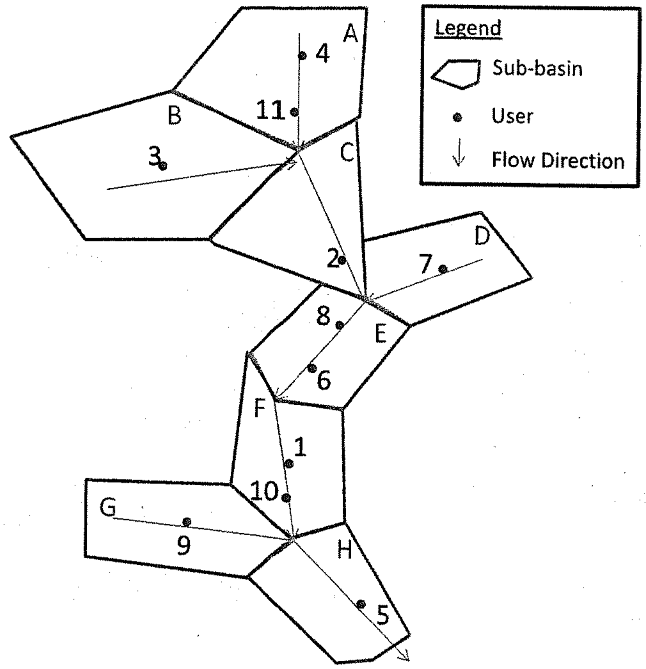

Fig. 2. Example watershed subbasins and users

Table 1. Subbasin Hydrology

Subbasin	Local inflow	Cumulative flow (v)	Environmental flow (e)	Flow available to allocate
A	7	7	1.4	5.6
B	7	7	1.4	5.6
C	7	21	4.2	16.8
D	7	7	1.4	5.6
E	7	35	7	28
F	7	42	8.4	33.6
G	7	7	1.4	5.6
H	7	56	11.2	44.8

Note: Flow units are volume/time.

Table 2. Riparian Model Results by User

User	Demand	Allocation	Proportion
R1	7	4.7	0.67
R2	4	2.7	0.67
R3	8	5.3	0.67
R4	8	2.5	0.31
R5	8	5.6	0.70
R6	4	2.7	0.67
R7	3	2.0	0.67
R8	9	6.0	0.67
R9	9	5.6	0.62
R10	7	4.7	0.67
R11	10	3.1	0.31

Note: Flow units are volume/time.

Table 3. Riparian Model Results by Basin

Basin	Allocation proportion	Availability	Upstream demand sum	Upstream allocation sum	Unallocated flow
A	0.31	5.6	18.0	5.6	0
B	0.67	5.6	8.0	5.3	0.3
C	0.67	16.8	30.0	13.6	3.2
D	0.67	5.6	3.0	2.0	3.6
E	0.67	28.0	46.0	24.2	3.7
F	0.67	33.6	60.0	33.6	0
G	0.62	5.6	9.0	5.6	0
H	0.70	44.8	77.0	44.8	0

Note: Flow units are flow/time.

Appropriative Allocation Formulation

After riparian water rightholders receive allocations, remaining available water is allocated to appropriative rightholders by strict priority. The following mathematical formulation represents the logic of priority-based appropriative water rights, without return flows. Allocation for a user i is given by the decision variable A_i, between a maximum use u_i and a minimum of zero

$$0 \leq A_i \leq u_i, \quad \forall\ i \tag{8}$$

Where a portion of use returns quickly to the subbasin, each use u_i can be adjusted to represent net consumptive diversion. More complex cases have been discussed by Israel and Lund (1999) and Ferreira (2007).

Similar to the mass balance for riparian users [Eq. (3)], the sum of all allocations upstream of a basin outlet cannot exceed the total water availability remaining after riparian allocations

$$\sum_{i \in k} A_i \leq v_k - e_k - b_k - \sum_{i \in k} A_{\text{upstream riparian users } i}, \quad \forall\ k \tag{9}$$

Unlike riparian rights, appropriative water rights are curtailed by strict individual priority. The earliest right in a basin has the highest priority, and the most recent right has the lowest. Priority establishes unit shortage penalties for all users. The unit shortage penalty (p_i) equals the number of users minus priority rank, so the highest priority user has the highest unit shortage penalty. Shortage for a user is the difference between demand u_i and allocation A_i.

The objective function minimizes total shortage penalty for all users [Eq. (10)]. Senior users have more weight in the objective function and are more likely to receive a full allocation. Likewise, junior users are less likely to receive an allocation

$$\text{Minimize } z = \sum_i p_i(u_i - A_i) \tag{10}$$

Appropriative Allocation Example

An appropriative allocation model was developed for the aforementioned example watershed (Fig. 2), with the same user and basin characteristics (Tables 1 and 2). Here, all users have appropriative rights, with User 1 having the highest priority and User 11 the lowest. User and basin results from the appropriative water rights allocation model appear in Tables 4 and 5. User 1, on the main stem and with the highest priority, receives a full allocation, whereas User 3, with a high priority but in the upper watershed, has less flow available. Thus, User 3 receives all flow available in Subcatchment B, but still sees shortage, running out of water before running out of right. User 4 similarly receives all available flow in Catchment A. User 11 in Catchment A has a low priority and receives no water. As demands of senior users are met, remaining available flow is allocated to junior users by priority. All available water was allocated to users, with no nonenvironmental flow leaving the system.

Table 4. Appropriative Model Results by User

User/priority	Demand	Allocation	Shortage
A1	7	7.0	0
A2	4	4.0	0
A3	8	5.6	2.4
A4	8	5.6	2.4
A5	8	8.0	0
A6	4	4.0	0
A7	3	3.0	0
A8	9	4.4	4.6
A9	9	3.2	5.8
A10	7	0	7.0
A11	10	0	10.0

Note: Flow units are volume/time.

Table 5. Appropriative Model Results by Basin

Basin	Availability	Upstream demand sum	Upstream allocation sum	Unallocated flow
A	5.6	18.0	5.6	0
B	5.6	8.0	5.6	0
C	16.8	30.0	15.2	1.6
D	5.6	3.0	3.0	2.6
E	28.0	46.0	26.6	1.4
F	33.6	60.0	33.6	0
G	5.6	9.0	3.2	2.4
H	44.8	77.0	44.8	0

Note: Flow units are volume/time.

Combining Water Allocation Methods

To assess allocations for basins with both riparian and appropriative water rights, the riparian linear program is run first, followed by the appropriative linear program. Riparians, having a higher priority overall, are less likely to be curtailed than appropriators (California has some rare cases of very old appropriative rights with potentially higher priority than riparian users; these can be handled by preallocation of water to such users before riparian allocations in very dry circumstances). Riparian rightholders in upper parts of the watershed are much more vulnerable to curtailment than downstream users. If any riparian is curtailed, all upstream riparians are consequently curtailed. Appropriators in upstream portions of watersheds are also more vulnerable to shortage because of low water availabilities and being curtailed to help meet downstream riparian demands.

Model Limitations

All users within a subcatchment k are assumed to have physical access to all inflow (v_k). But some local inflow will enter downstream of some local users, restricting their access to some flow. This misrepresentation is reduced with increasing the spatial resolution of subcatchments. Ideally, each user would have a defined subbasin, but this would greatly enlarge the problem. Error also could be reduced by restricting each user to the percentage of total subbasin outflow available at the user's point of diversion. Also, some users have multiple points of diversion.

The maximum allocation for each user is their previous use u_i, reported under historical flow conditions. These may be less relevant during drought. Ideally, during drought water users would announce or call diversions for their right before each time period, allowing water right administrators to make more accurate and timely water allocations.

In times of drought, curtailed water users often replace lost surface-water allocations with groundwater. However, DWRAT only includes surface-water allocations and omits groundwater depletion effects on surface-water availability. This may overestimate water availability, especially in longer droughts.

DWRAT currently omits return flows back to surface water. This reduces downstream water availabilities. Water uses such as hydropower and flood irrigation have high return flows to surface water. Israel and Lund (1999), Ferreira (2007), and Chou and Wu (2014) presented methods for developing priority-based penalty coefficients for network flow and linear programming models of water resources systems with return flows and appropriative rights. These algorithms could serve as preprocessors to account for return flows while preserving water rights priorities, or net surface-water diversions could be used, assuming local return flows.

Another limitation is that estimates of water availability, use, and return flows are imperfect. Buffer flow represented in the mass balances [Eqs. (3) and (9)] can provide a factor of safety by modifying availability. Positive buffer flow values decrease availability and increase curtailments, but reduce likelihood of overpromising water. Conversely, negative buffer values reduce curtailments, but are likely to overpromise water and increase likelihood of senior rightholders being deprived of water. Errors cannot be entirely eliminated or even entirely known without extensive monitoring. Higher buffer values increase the likelihood of false curtailments (when water is actually available), whereas lower (or negative) buffer flows increase false promises (when water is not actually available for a noncurtailed rightholder). Effects of uncertainty can be explored by varying the buffer flow to see the range of curtailments generated.

Estimating Water Right Reliability

This section introduces a preliminary approach for estimating water supply reliability for individual water rightholders given hydrologic variability. By varying the flow and conducting probabilistic analysis of results from DWRAT, the reliability of water allocations can be estimated for a set of users. The presented methods estimate the probability of water right curtailment in a basin given an uncertain basin outflow hydrology, with known net diversions and a fixed spatial distribution of water availability.

Any unimpaired outlet flow Q_n with a known distribution of local subbasin inflows has a corresponding legally required set of curtailments $[C_n]$ composed of binary values 0 or 1 for each water rightholder i, calculated by the methods discussed earlier. When $C_i = 1$, user i is curtailed and receives less than their full water allocation. Uncurtailed users ($C_i = 0$) receive full allocations. Monte Carlo analysis and implicit stochastic optimization were used to estimate the probabilities of curtailment for individual users.

In Monte Carlo analysis, model input parameters are sampled from a probability distribution. For each sample, model output is recorded. This process is repeated many times to sample a large range of possible input values with realistic relative frequencies. Frequency analysis on the full set of model outputs can estimate the likelihood of a given curtailment solution over the range of possible input values.

For small or simple basins, water right reliability can be estimated by varying inflow over a probability distribution. For each outlet flow, the optimal curtailment set $[C_n]$ is calculated. The reliability of each right is the probability that there is a corresponding outflow which supplies that right, calculated either by numerical integration or by the ratio of samples where user i is curtailed divided by the total number of Monte Carlo samples.

Operating water systems under uncertainty can be complex and computationally intensive. Numerical estimation of uncertainty can be prohibitively complex. Implicit stochastic optimization (ISO) can reduce these problems by applying deterministic modeling over a representative range of input parameters. Initially, a representative range of model input parameters is generated. For each set of inputs, the model generates a single solution set. The probability of any solution is the probability of its corresponding inputs. Frequency analysis over the set of solutions estimates probabilities of curtailment.

Perhaps more useful, the full solution set can help establish a set of rules for real-time system curtailments. Administrators could observe current conditions and look up the corresponding optimal curtailments from the ISO results without additional model runs. ISO is most often used to identify operating rules for reservoirs with uncertain inflows (Young 1967; Lund and Ferreira 1996). Operations are optimized over a long representative time-series of inflows with perfect foresight using deterministic methods. The results are then used to infer optimal operating rules.

For this application of ISO, stochastic operation of a water rights system is considered from administrator and user perspectives. To estimate water right reliability with ISO, a range of outlet flows Q_n is selected. DWRAT calculates $[C_n]$ for each outlet flow Q_n. The probability of a curtailment occurring is the probability of the lowest Q_n when the curtailment occurs. For simple systems, each user i has a corresponding curtailment threshold flow Q_{ti}. When the outlet flow is below Q_{ti}, user i is curtailed and receives less than a full allocation. By stepping through a range of Q_n values and solving the allocation models, the curtailment threshold flow can be identified for each user. The probability of a user curtailment is the probability of Q_{ti}.

Example Basin

The example watershed in Fig. 2 was extended to test and illustrate these methods with a mix of riparian and appropriative users. The basin has eight subbasins (denoted A–H), with local flow availability v_k equal to the outlet flow (Basin H) multiplied by the ratio of upstream drainage area (a_k) to total basin drainage area [Eq. (11)]

$$v_k = Q_n * \frac{a_k}{a_{k,\text{outlet}}} \tag{11}$$

Outlet flow is normally distributed (for illustration) with a mean of 60 and standard deviation of 30, truncated at zero. Other flow distributions could be used. Local inflows to each subbasin are assumed to be a fixed fraction of unimpaired outlet flow. Users R1 through R5 have riparian rights (equal priority). Users A1 through A11 have appropriative rights and with priority given by their label number (A1 has highest priority). Fig. 3 shows the users' locations and Table 6 provides demand for each user (method results are in lower rows).

Another way to represent the system is to view cumulative demand ranked by priority, as indicated in the second-to-bottom row of Table 6. For a riparian user, cumulative demand is the sum of all riparian demand. For an appropriative user, cumulative demand equals the summed demand of higher priority users.

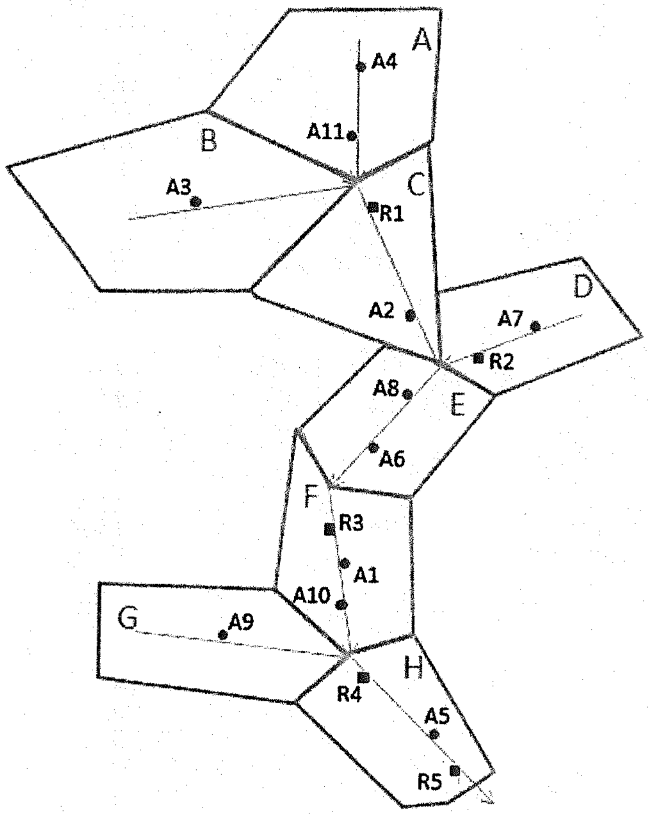

Fig. 3. Example basin with users

If all users had equal access to outlet flow, cumulative demand for user i would be the total amount that must be allocated before user i receives any water. However, the spatial variability of supply disrupts this relationship. This metric is most useful for appropriative rightholders because of their clear relative prioritization.

Monte Carlo Analysis Application

For the Monte Carlo analysis, $[C_n]$ was calculated for a randomly sampled Q_n from the normal error distribution. This process was repeated 500 times to form a statistically representative set. Frequency analysis over all sets of $[C_n]$ determined the reliability of water allocation for each user. The results of the frequency analysis appear in the lowest row of Table 6.

Table 6. Example Users and Demand

User (ordered by priority)	Demand	Cumulative demand	Probability of shortage, Monte Carlo
R1	4	27	0.105
R2	6	27	0.390
R3	8	27	0.105
R4	2	27	0.105
R5	7	27	0.105
A1	7	34	0.190
A2	4	38	0.230
A3	8	46	0.555
A4	8	54	0.555
A5	8	62	0.535
A6	4	66	0.565
A7	3	69	0.630
A8	9	78	0.75
A9	9	87	0.80
A10	7	94	0.875
A11	10	104	0.995

Probability of curtailment increases as priority decreases, with some deviations. Riparian users have the lowest probability of curtailment. However, User R2 is on a tributary branch and is much more likely to face local shortages than other riparian users. Similarly, Users A3 and A4, high in the watershed, have higher probabilities of shortage than A5, with lower priority but on the main stem near the outlet. Users A3 and A4 have the same shortage probability, despite A3's higher priority. Both users are on separate tributaries with independent availabilities, so the availability in Basin A is less affected by water availability or curtailments in Basin B, and vice versa. Users A3 and A4 are limited by availability and location, whereas User A5 is limited by priority.

Implicit Stochastic Optimization Application

To estimate water right reliability with implicit stochastic optimization, $[C_n]$ was calculated for each outlet flow Q_n ranging stepwise from 0 to 150 in increments of 1. As outlet flow increases, fewer users are likely to be curtailed, as shown in Fig. 4. Each step in Fig. 4 corresponds to a user or set of users receiving a full allocation. The flow value corresponding to the step at which a user receives a full allocation is the curtailment threshold flow Q_{ti}. When outlet flow is below Q_{ti}, user i is curtailed. If all users have access to outlet flow, the curtailment threshold would be the cumulative demand for all users. Varying spatial flow availability disrupts this relationship.

Fig. 5 shows the cumulative demand and curtailment threshold for each user, assuming fixed ratios for subbasin inflows to total basin unimpaired outflow. As a user's priority decreases, the corresponding cumulative demand and curtailment threshold increases. Users along the main branch of the river basin (Subcatchments C, E, F, and H) have more access to flow and are less likely to see local supply shortages. Curtailment for these downstream users is generally dictated by priority. In Fig. 5, cumulative demand and curtailment threshold values for these users are nearly equal. Users in the upper portions of the basin (Subcatchments A, B, D, and G) are more likely to face curtailment from local flow shortages. This effect occurs for R2, A3, and A11, whose curtailment threshold significantly exceeds cumulative demand. User R2, despite sharing the highest priority with other riparians, diverts in a subbasin (Basin D) that is more likely to receive shortage. Because local flow availability is proportionate to outlet flow, User R2's curtailment flow threshold is the outflow sufficient in Basin D to meet R2's demand. Their upstream locations make them more vulnerable to curtailment than similar priority users downstream.

The probability of curtailment for a user i is then calculated as the probability that Q_n is less than or equal to Q_{ti}, the cumulative probability distribution function for Q. Fig. 6 shows the probability of curtailment for each user, calculated by the ISO method. The Monte Carlo and ISO methods yield nearly identical curtailments. With more Monte Carlo iterations, the results should converge.

The probability of a individual water right curtailment depends primarily on priority and location in the watershed. The results represent the probability that a water right should be curtailed given the forecast water availability Q and normally distributed error σ. However, actual probabilities of curtailment will differ from errors in estimating water demands, overall water availability, and its spatial distribution.

The presented methods might provide curtailment rules for water right administrators. When flow or forecasted flow at a

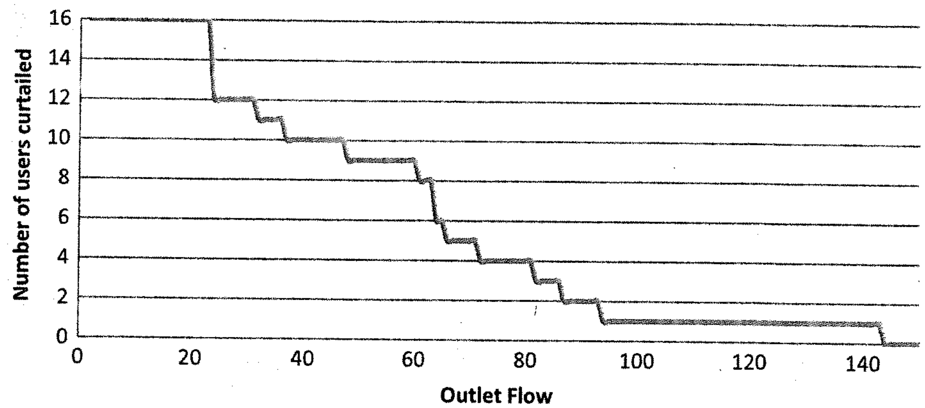

Fig. 4. Total number of curtailed users by outlet flow value

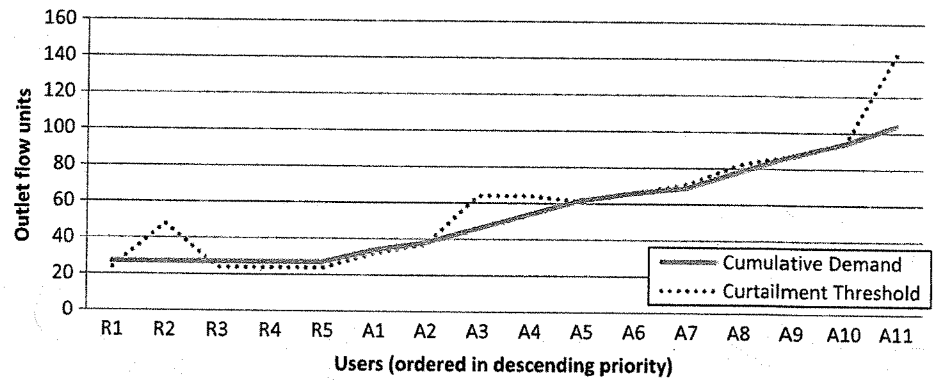

Fig. 5. Cumulative demand and curtailment threshold for all users

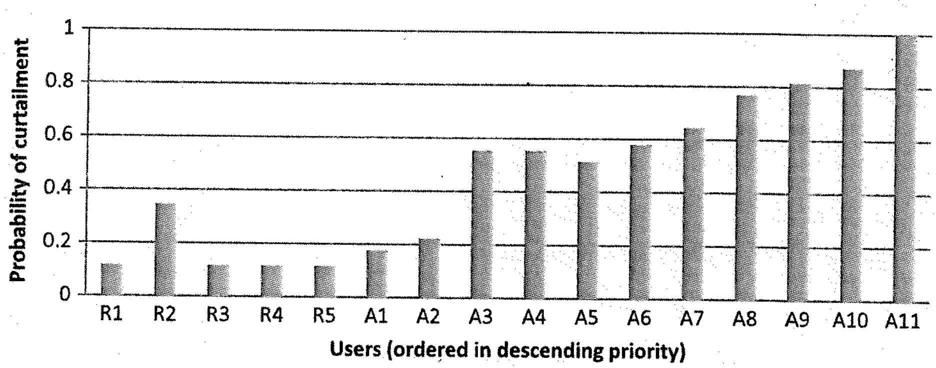

Fig. 6. Probability of curtailment for each user from implicit stochastic optimization method

nearby gauge is below a specified value, some users are not allowed to divert water. This method of assigning curtailments has several advantages. DWRAT would no longer need to be run every time period for an entire basin, given known curtailment thresholds based on flow rates. Users would benefit from knowing the probability of curtailment, allowing for better planning of diversions.

Buffer Flows

Uncertainty in hydrologic forecasting can increase curtailment errors. Curtailments are likely to be calculated in advance based on a forecasted available flow and anticipated user diversions. However, actual flow and diversions may differ significantly, leading to errors in allocations. Including buffer flows can adjust curtailments for forecasting uncertainty by artificially reducing (or increasing) water availability. A higher positive buffer flow is a safety factor for senior rightholders to reduce the chance that water will be unavailable for them or environmental flows. However, this buffer requires additional curtailments for more junior rightholders. The methods discussed next review errors caused by uncertainty and provide a framework for balancing buffer flow values and uncertainties.

False Promises

When actual flow is less than forecasted, some users will be promised a full allocation, but will not have enough water available. Such false promises of water decrease with greater buffer flows. The average number of false promises $E(FP)$ can be defined

$$E(FP) = \int_0^{\infty} P(Q_{\text{act}})FP(Q_{\text{for}}, Q_{\text{act}}, B)dQ_{\text{act}} \tag{12}$$

where

$$FP(Q_{\text{for}}, Q_{\text{act}}, B) = \text{Maximum}\begin{cases} C(Q_{\text{act}}) - C(Q_{\text{for}} - B) \\ 0 \end{cases} \tag{13}$$

Eq. (12) is the expected number of false promises over possible actual outlet flows Q_{act}, given a forecasted outlet flow Q_{for} and an outlet buffer flow B. False promises for a particular circumstance are defined in Eq. (13) as the difference between number of curtailments with the actual flow and number of curtailments with the forecast flow minus the buffer.

False Curtailments

Buffer flows increase cases when some users suffer curtailments, when the basin had sufficient flow for them to take water. These false curtailments increase with buffer flow values. Given the nomenclature defined earlier, the expected false curtailments $E(FC)$ can be defined

$$E(FC) = \int_0^{\infty} P(Q_{\text{act}})FC(Q_{\text{for}}, Q_{\text{act}}, B)dQ_{\text{act}} \tag{14}$$

where

$$FC(Q_{\text{for}}, Q_{\text{act}}, B) = \text{Maximum}\begin{cases} C(Q_{\text{for}} - B) - C(Q_{\text{act}}) \\ 0 \end{cases} \tag{15}$$

Eq. (15) defines false curtailments as the difference between forecasted curtailments including buffer flow, and the ideal optimal curtailments with the actual outlet flow. Given uncertainty in water availability, there is always a likelihood of false promises and false curtailments, the balance of which is implicit in water rights administration policies and methods.

Example Basin Application

Eqs. (12) and (14) were applied to the example basin with varying buffer flows and an outlet flow forecast of 60. Fig. 7 illustrates the effect of increasing buffer flows. With no buffer flow, 1.1 false promises and 2.6 false curtailments can be expected. Larger buffer flows make false curtailments more likely and false promises less likely. At a buffer flow exceeding 40, only 20 units of flow are available for allocation and the number of false promises and curtailments stabilizes as all users are curtailed.

Selecting a proper buffer flow may vary with the policy balancing of water rights administrators. If a basin administrator seeks to minimize total falsities, a buffer flow of zero would be optimal. However false promises may be more damaging than false curtailments (or vice versa). In this situation, a buffer flow that would decrease the probabilty of false promises would be optimal, but at the cost of increasing false curtailments.

Here, only positive buffer values are evaluated. Negative buffer values, which would increase supply, would reduce the number of false curtailments and increase the number of false promises. If a water rights administrator seeks to minimize falsities, a range of buffer flow values should be explored. Also, only uncertainty in outflow is examined here. Other sources of uncertainty should be explored, such as subbasin flow distribution and water demand.

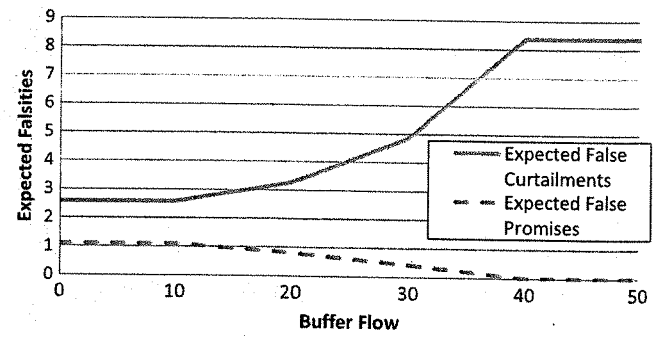

Fig. 7. Expected false promises and curtailments with varying buffer flow

Methods for identifying probability of curtailment could be extended further. Monte Carlo analysis could identify users most likely to face false curtailments or false promises. False promises could result from upstream users withdrawing more than allocated, resulting in a physical absence of water for downstream users.

Applying DWRAT in the Eel River

The Eel River is the first basin for which DWRAT has been developed for application. The Eel River watershed on California's North Coast region has rugged terrain and a low human population density. The basin has an average annual precipitation of 1,524 mm (60 in.), largely from November through March, and is mostly undeveloped. Lake Pillsbury and its forebay, Van Arsdale Reservoir, are the only significant storage projects. At Van Arsdale Reservoir, flow is diverted to the Russian River watershed via the interbasin Potter Valley Project (PVP).

Water Availability and Demands

The USGS operates 11 gauges in the Eel. The lowest elevation gauge, at Scotia, has records dating back to 1911, with a mean annual flow of $35,524,224$ m^3 (28,800 acre/ft/day).

Allocations in DWRAT rely on natural surface-water flow estimates at the 12-degree Hydrologic Unit Code (HUC12) scale. The National Weather Service (NWS) operates flood gauges quantifying natural flow at three locations in the Eel River: Scotia, Fort Seward, and immediately downstream of Lake Pillsbury (ordered from downstream to upstream). A statistical model extrapolates these unimpaired NWS flows to all ungauged HUC12 outlets using ratios of gauged to ungauged flow from a random forest model based on the USGS Gauges-II database that predicts historical monthly flows at ungauged HUC12 locations (Carlisle et al. 2010). A series of scaling factors was calculated using these historical monthly flows. The scaling factors were then used to predict flow at ungauged locations with measured or forecasted flow at gauged locations (Lord 2015).

Water rights information on type of right, date of first use, and 2010–2013 monthly reported withdrawals for the Eel River is available from the SWRCB's Electronic Water Rights Information Management System (2014). The data set contains 206 riparian, 30 pre-1914 appropriative, and 447 post-1914 appropriative rights. Average monthly consumptive water demand is estimated by averaging the 4 years of use data and removing hydropower and other fully nonconsumptive diversions. Daily demand is estimated in DWRAT by dividing the average monthly reported use by the number of days per month. This introduces some error because water

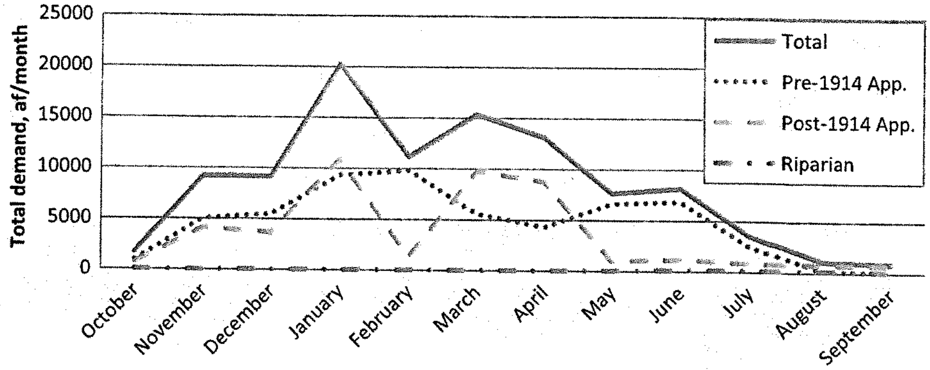

Fig. 8. Monthly water demand in the Eel River Basin according to Howard (2014)

users rarely divert the same amount each day of a month. Fig. 8 shows total average monthly demand for each water right category.

June 30, 2014, Curtailments

On June 30, 2014, the SWRCB announced curtailments for all post-1914 water rights in the North Fork Eel River, Main Stem Eel River, and Van Duzen Tributary, with some exceptions. Curtailments could only be lifted once the SWRCB determined that "water is legally available for diversion under [a user's] priority of right" (SWRCB 2014).

Table 7 summarizes the demand, by user group, for June 30. Of the 683 rights, 419 have non-zero demand for the day and are considered active. The remaining 264 inactive rights have zero demand are excluded from the model. Pre-1914 appropriative rights are most use by volume, followed by post-1914 rights and riparian rights. Fig. 9 shows the June 30 cumulative demand for all rights in the Eel River.

Table 7. Eel River Water Demand, June 30

Right type	Number of active users (% of total)	Demand, af/d (% of total)
Riparian	158 (38%)	4.6 (2%)
Pre-1914 appropriative	25 (6%)	228.0 (84%)
Post-1914 appropriative	236 (56%)	39.5 (14%)
Total	419 (100%)	272.2 (100%)

Water use volume for June 30 in the Eel River is dominated by a few rights owned by the Pacific Gas and Electric Company (PG&E) for the PVP, which transfers water from the Eel's headwaters to the Russian River's East Fork for hydroelectric power. The two largest rights are Applications S001010 (231st in priority, first use in 1905 with June 30 estimated demand of 223.8 acre-ft/day—82% of total demand) and A006594 (249th in priority, first use in 1930 with June 30 estimated demand of 15.5 acre-ft/day).

DWRAT was used to estimate optimal curtailments for June 30, 2014, in the Eel River, with no buffer or environmental flows. A total of 126 rights were curtailed (30% of all users). Curtailments included 46 riparian rights (29% of riparians), 6 pre-1914 rights (24% of pre-1914s), and 74 post-1914 rights (31% of post-1914s). In total, 24.9 acre-ft of water were allocated. Most curtailments were in HUC12 basins where supply is calculated using the NWS gauge at Lake Pillsbury, which had an unimpaired flow of zero. This resulted in zero water available for allocation in all dependent HUC12s. Approximately 75% of curtailed rights are in this part of the watershed, including the large Potter Valley Project diversions.

The SWRCB curtailed diversions for all post-1914 appropriative users, regardless of location in the watershed. The curtailments proposed in DWRAT incorporate spatial variability of flow and limit allocations where supplies are lowest. Many post-1914

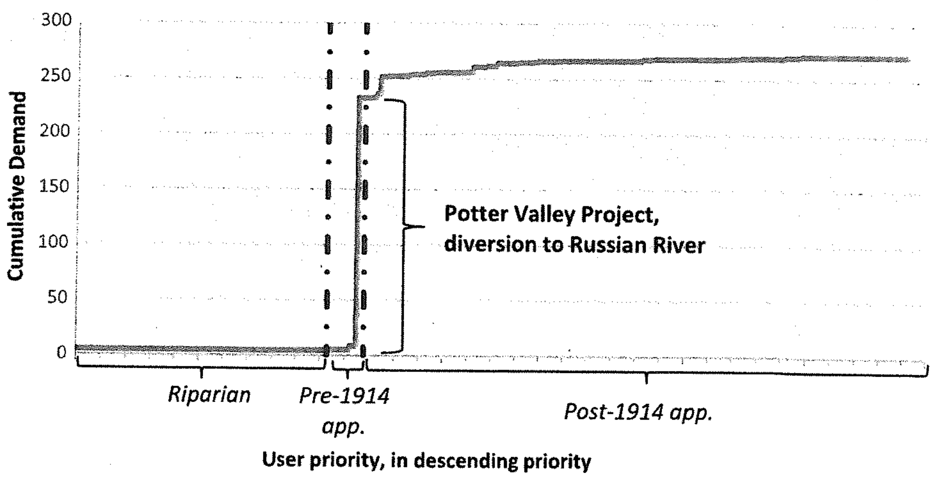

Fig. 9. June 30 cumulative water demand

appropriative users received full allocations using DWRAT, particularly in downstream locations. The shortage was allocated nearly proportionately among user classes and depended more on location than priority of right.

Extended DWRAT Application

DWRAT was used to calculate June 30 curtailments in the Eel River for previous historical years. The NWS only began providing unimpaired gauge flow estimates in 2014, so an alternative source of unimpaired flows was developed. Three USGS impaired flow gauges near the NWS sites were selected. The gauge at Scotia has the longest record, dating to 1911. The other two stations, at Fort Seward and Lake Pillsbury, have much shorter records. Regression analysis was used to develop a trend for the overlapping records between these two stations and the Scotia gauge. The trend was extended over the entire historical record to generate the synthetic impaired flows, with estimated diversions then returned to estimate 102 years of unimpaired flows (Lord 2015). DWRAT was then used to estimate curtailments for June 30 of each year using the synthetic unimpaired flows from 1911 to 2014.

Of the 102-year synthetic unimpaired streamflow record, 88 years would have some curtailments on June 30. By comparison, the SWRCB has only issued curtailments once before 2014. The more frequent curtailments of DWRAT are caused by several factors. DWRAT evaluated curtailments with average 2010–2013 monthly demand over the entire period. Historical water use rates may have been much less. Also, DWRAT omits surface-water return flows, resulting in decreased availability. However, most of the large appropriative rights are fully consumptive to the basin, and most other water use is in the northern part of the basin near the outlet where supplies are plentiful, reducing the potential benefit from return flows. The high frequency of curtailments also is affected by DWRAT's exclusion of water released from storage, underestimating flow availability for appropriative rightholders. Errors also occur in gauge flow estimates and the spatial distribution of flows.

Most curtailments occur in subbasins dependent on the Lake Pillsbury gauge flow for flow extrapolation. It was found that 2014 is the only year with zero flow at this gauge, as well as the only year with a NWS unimpaired flow value. The PVP is in this group of basins. The combination of low predicted flows and a nearby extremely large, senior water right results in consistent curtailments for this part of the watershed. If the highly senior PVP right is curtailed, almost all other appropriative water rights in this region also will be curtailed.

Implicit Stochastic Optimization

The method developed in preceding sections to estimate curtailment thresholds was applied to the Eel River. To simplify analysis, flows at Fort Seward and Lake Pillsbury were calculated as a function of flow at Scotia, using regression equations, and assuming constant proportionality of flow in all subbasins, making flow in all HUC12 subbasins a function of Scotia flow (Lord 2015). Optimal curtailments were calculated for a range of flows at Scotia. Fig. 10 shows the number of users curtailed over the range of flows.

The function shown in Fig. 10 was expected to decrease monotonically, with the total number of curtailed users never increasing with additional supply. Although the curtailments predominantly decrease with increasing unimpaired flow at Scotia, the number of curtailed users increases slightly at 12 points. This behavior occurs at flows ranging from 50 to 100 and 800 to 850. However, the total volume of curtailed water (difference between total demand and total allocations) always decreases monotonically. The cause

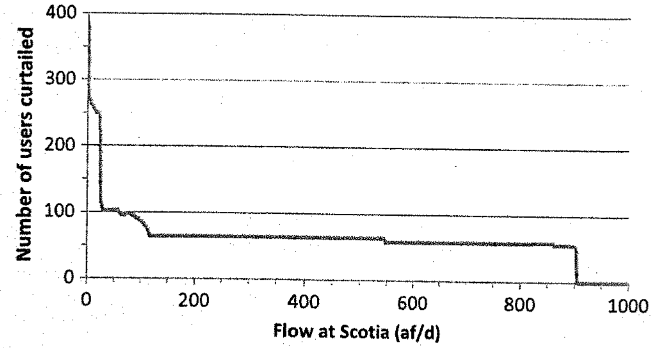

Fig. 10. Number of users curtailed by flow at Scotia, June 30

of the rising curtailments with increased supply is unclear. Rights experiencing this curtailment with increased water availability are mostly appropriative. Further work is needed to determine why curtailment numbers (but not volumes) sometimes increase slightly with increased water availability.

Calculated curtailment thresholds had little correlation with cumulative demand or priority, particularly for appropriative users. Optimal curtailments in the Eel are largely determined by location in the watershed rather than priority of right. Water rights for the PVP dominate allocations. Users downstream of the PVP have low curtailment thresholds and low probabilities of curtailment. Users upstream of the PVP are much more likely to be curtailed to preserve flow for senior downstream users. Basinwide curtailments by priority date will not allocate the most water possible because of spatial variability in water availability, priority, and demand in the Eel. To ensure maximum allocations, curtailments could be issued at a finer spatial scale by priority date. The presented methods could locate areas of large basins likely to face shortage, minimizing the likelihood of downstream false curtailments.

This representation of the Eel River's hydrology is greatly simplified. Flow for the entire river is calculated from availability at Scotia. A better hydrologic model could improve calculations of optimal curtailments and probabilities. Also, return flows should be incorporated. Assuming all use is consumptive artificially reduces availability and increases curtailments. Using past reported water use as a basis for estimated water demands is also a source of error, as found by Grantham and Viers (2014).

Conclusions, Limitations, and Further Research

DWRAT enables precise calculation of water right curtailments during drought by incorporating spatial variability of flow, demand, and priority into a mathematical framework representing the logic of California water law. Although the 2014 drought was significant, more dry years will occur. DWRAT provides an explicit, transparent, mechanistic, and rigorous method for calculating water right curtailments in a mixed water right system using public data and software. It can help support more transparent curtailments and prepare water right administrators for future dry conditions. The curtailment threshold method may be an alternative timely means for issuing curtailments. All users in smaller basins could be told of a specified curtailment threshold value for a nearby gauge. When gauge flow falls below that value, a user will know not to withdraw water to preserve downstream supply.

DWRAT is structured for any temporal or spatial scale large enough where dynamics and hydraulic routing are unimportant. However, curtailments calculated by DWRAT are only as good

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as the data used. Improvements can be made in both water supply and demand data.

Currently, only monthly withdrawals are available through the SWRCB's databases. Daily demand is estimated in DWRAT by dividing the monthly demand by number of days. This may be reasonable for some users, such as municipalities, but it can be unreliable. Irrigation is rarely distributed evenly across a month. However, asking rightholders to report daily use is unrealistic today. Instead, large users could call use of their rights in advance of an expected curtailment date during extreme dry periods. DWRAT could estimate curtailments based on the updated demand data. Both the SWRCB and users would benefit from this arrangement. Users would benefit from the ability to plan water use in advance and fuller basin water use. The SWRCB would benefit from a transparent and flexible system with explicit and timely water rightholder input.

Limited data exist on return flows. Rights associated with in-stream hydropower uses have zero consumptive demand in DWRAT, but nonconsumptive use from other sources is not yet considered. For rights with return flows rejoining the basin near the point of diversion, allocations could be based on consumptive use rather than total withdrawal. Rights where return flows return to supply far from the point of diversion, such as interbasin transfers through hydropower, present a larger challenge, but might just be considered as fully consumptive from surface-water availability. Several studies (Israel and Lund 1999; Ferriera 2007; Chou and Wu 2014) have presented methods for adjusting penalty coefficients for appropriative users to address this problem, but the method may be too complex for large systems, and data on return flow locations may be difficult to acquire.

Water availability is estimated statistically, using discrete NWS full natural flow forecasts and a spatial extrapolation model. DWRAT does not include water released from reservoirs, which is available for appropriative rightholders. In large systems with multiple reservoirs, such as the Sacramento River, this can be an important supply source. Current versions of DWRAT lack this capability, but reservoir releases could be added to appropriative availability.

DWRAT is an algorithm for implementation of water rights law in California. By accounting for spatial variability in demand, supply, and priority, curtailments can be suggested with greater precision. Given that California faces future droughts, tighter water rights administration will be necessary. Tools such as DWRAT can add transparency, rigor, and accuracy to better address the needs in future dry years.

Acknowledgments

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PRU and R-GPCD Calculation

September 22, 2020

This document contains suggested methods for estimating Percentage Residential Use (PRU), and explains how daily residential per capita water use (R-GPCD) is calculated by Water Board staff. As of October 1st, 2020, the R-GPCD is automatically calculated in the reporting tool. The methodology outlined here has not changed since the initial guidance was developed for the emergency conservation regulations.

When estimating PRU, we recommend using billing data to determine the volume of water provided to residential customers as a percentage of Total Monthly Potable Water Production. In cases where billing periods are not based on calendar month, the urban water supplier should use discretion in selecting the most comparable and appropriate billing period. PRU, rather than residential use volume, is requested in the monthly conservation report because it can be calculated using the previous year's data if current billing data is not available.

Example PRU Calculation: Using recent billing data to estimate PRU

Total Production (T): 1543.98 Acre-feet (AF)

Commercial Agriculture (C): 20 AF

Residential Use (R)[1]: 1001.42 AF

1. Subtract Commercial Agriculture (if any) from Total Production

$$Total\ Production, minus\ Agriculture\ (TPA) = T - C$$

$$TPA = 1543.98 - 20 = 1523.98\, AF$$

2. Divide Residential Use by (Total Production – Commercial Agriculture)

$$PRU = \frac{R}{TPA} \times 100$$

$$PRU = \frac{1001.42}{1523.98} \times 100 = 65.71\%$$

If you do not have billing data for the current reporting month, use last year's data (**BOTH** residential use and total potable production) for the month that corresponds to the reporting month. For example, if you do not currently have October 2020 billing data available, use October 2019 data. **This calculated PRU using last year's data should be entered in the "Preliminary" column when submitting a report.**

[1] When estimating "Residential Use," we recommend using billing data to determine the volume of water provided to residential customers. In cases where billing periods are not based on calendar month, the urban water supplier should use discretion in selecting the most comparable and appropriate billing period.

Once you have current billing data, re-calculate the PRU using current numbers and enter the new value in the "Final" column of the edited report.

Example PRU Calculation: Bi-Monthly Billing Cycle Initial Estimate

Total Production (T) Over Billing Cycle: 3002.15 AF

Commercial Agriculture (C) Over Billing Cycle: 35 AF

Residential Use (R) Over Billing Cycle: 1900.23 AF

Length of Billing Cycle: 61 days

Reporting Month: May

Days in May: 31 days

1. Subtract Commercial Agriculture (if any) from total production

$$Total\ Production, minus\ Agriculture\ (TPA) = T - C$$
$$TPA = 3002.15 - 35 = 2967.15\ AF$$

2. Calculate Residential Use for Reporting Month (RM) and Total Production for Reporting Month (TPM)

$$TPA\ for\ May\ (TPM) = \frac{TPA \times days\ in\ May}{days\ in\ billing\ cycle}$$
$$TPM = \frac{2967.15 \times 31}{61} = 1507.90\ AF$$
$$R\ for\ May\ (RM) = \frac{R \times days\ in\ May}{days\ in\ billing\ cycle}$$
$$RM = \frac{1900.23 \times 31}{61} = 965.69\ AF$$

3. Divide Residential Use for Reporting Month by (Total Production – Commercial Agriculture) for Reporting Month

$$PRU = \frac{RM}{TPM} \times 100$$

$$PRU = \frac{965.69}{1507.90} \times 100 = 64.04\%$$

Please note in the "Qualification" box that the billing data is bi-monthly. As with the previous PRU calculation example, if you do not have billing data that encompasses the current reporting month, please use billing data from the previous year to estimate PRU and enter the value in the "Preliminary" column.

Example Residential Gallons Per Capita Daily (R-GPCD) Calculation

The updated reporting tool automatically calculates the monthly R-GPCD value. The calculation methodology is outlined below.

Original Units	Conversion Factor (CF) from Original Units to Gallons
Gallons (G)	1
Million Gallons (MG)	1000000
Hundred Cubic Feet (CCF)	748.052
Acre Feet (AF)	325851

Total Production (T): 1543.98 AF

Commercial Agriculture (C): 20 AF

Percentage Residential Use (PRU): 65.71%

Population (P): 69078 people

Month: May

Days in Month: 31 days

Conversion Factor (CF): 325851

1. Subtract Commercial Agriculture (if any) from Total Production
$$Total\ Production, minus\ Agriculture\ (TPA) = T - C$$
$$TPA = 1543.98 - 20 = 1523.98\ AF$$
2. Convert (Total Production-Commercial Agriculture) to Gallons, using the Conversion Factor
$$TPA\ in\ Gallons\ (TG) = TPA \times CF$$
$$TG = 1523.98 \times 325851 = 496590407\ G$$
3. Multiply the Total Production Gallons by Percentage Residential Use to get Residential Use in Gallons
$$Residential\ Use\ in\ Gallons\ (RG) = TG \times \frac{PRU}{100}$$
$$RG = 496590407 \times \frac{65.71}{100} = 326313708\ G$$
4. Divide Residential Use by (Population x Days in Month) to get R-GPCD
$$R - GPCD\ for\ May = \frac{RG}{P \times days\ in\ May}$$
$$R - GPCD\ for\ May = \frac{326313708}{690798 \times 31} = 152.38\ GPCD$$